

## Evaluating the degradability of non-argillaceous porous rock

### Evaluación de la degradabilidad de rocas porosas no arcillosas

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**ABSTRACT:** The conventional slake durability test is routinely used to qualitatively evaluate the durability of weak argillaceous rocks through softening and disintegration, leading from a standard two cycles of wetting and drying in the service environment. In the present study, the test was employed for quantifying the slake durability of a non-argillaceous porous limestone, a carbonate rock from the Silurian Wabash formation in Indiana through which a tunnel project was implemented. The standardized test procedures did not lead to significant/noticeable degradation. Hence, a number of parameters were varied in the subsequent series of tests and their sensitivities on the test results were documented. These parameters include: (1) the number of wetting-drying cycles, (2) acidity of the solutions used for wetting the samples, (3) duration of soaking periods prior to the tumbling cycles, (4) sample tumbling duration, and (5) sample drying procedures. Preliminary results presented in this paper indicate that degradability correlates well with the number of cycles and acidity of the solution. The outcome from investigating the influence of sample soaking and tumbling duration and their drying procedure on degradability was inconclusive, warranting additional research.

**KEYWORDS:** slake durability test, pH, slake durability index, dolomite.

## 1 INTRODUCTION

Porous bedrock exposed to wetting-drying cycles is susceptible to rapid deterioration of its physical and mechanical properties. In carbonate rocks such as limestone and dolomite, degradation is enhanced by the presence of slightly acidic fluids that tends to dissolve their minerals and enlarge fractures and pore space. This, in turn, induces more fracturing, and ultimately controls the rate of water circulation through the rock. Overall, these changes reduce rock strength, causing adverse effects such as slope instabilities and challenges for civil projects, such as the construction of shallow foundations, or underground structures (such as tunnels). Other projects susceptible to stability problems due to rocks exposed to cyclic wetting-drying cycles are those near coastlines, or water/oil pumping reservoirs. Thus, understanding the impact of weathering in the physical properties of rocks as a result of wetting-drying cycles is essential to assess and predict their long-term mechanical behavior for design purposes, and to ensure the durability and safety of civil infrastructure and rock engineering projects.

Different factors affect the rate of rock degradation upon wetting and drying, such as internal stresses induced by fluctuations in rock volume due to cycles of hydration and dehydration (Panthi, 2006; Okamoto, 1993), weakening effects of water at different degrees of saturation (Bauer et al., 1981; Wong et al., 2016), thermal-induced stresses (Hu et al., 2017), or the pH of the solution in contact with the rock (Gupta and Ahmed, 2007; Singh et al., 2005 and 2006; Torabi-Kaveh 2022; Yagiz 2018). Excavation methods (ex: drill vs. blasting) will also contribute significantly to the degradation of rocks (Selen et al., 2019). These factors will affect the durability of rocks at different degrees

depending on their mineral composition, texture, and porosity (Jaques et al., 2020; Lasheen et al., 2023; Quiao et al., 2023).

Degradability of rocks due to chemical and mechanical processes is known as slaking (Franklin and Chandra, 1972), and is related to the chemical breakdown of the rocks (due to hydration, evaporation, dissolution, oxidation) in combination with other physical processes such as abrasion. Tests to evaluate the durability of rocks include the jar slake test, the slake index test, and the slake durability test. The last one, proposed by Franklin and Chandra (1972) has been standardized (ISRM, 1979; ASTM D4644-16), and is routinely used to qualitatively assess the durability of soft clay-bearing rocks through softening and disintegration. In the last two decades, the test has also been used to assess the degradability of non-argillaceous rocks such as pyroclastic rocks and tuffaceous sandstone (Dhakal et al., 2002), basalts (Soares et al., 2002), sandstone (Moradian et al., 2010; Ghobadi and Mousavi, 2014; Liu et al., 2020), granite (Ghobadi and Momeni, 2011), limestone (Yagiz, 2011a, 2011b and 2018; Khandelwal, 2013) or hornfels (Ghobadi and Fereidooni, 2015). Non-clay-bearing rocks are less sensitive to wetting and drying cycles than argillaceous rocks. Therefore, several authors have proposed modifications to the standardized slake durability test in non-argillaceous rocks by increasing the number of wetting and drying cycles and/or using different types of slaking solution (e.g. Dhakal et al., 2002; Nikudel et al., 2011; Ghobadi and Mousavi, 2014; Khajevand and Fereidooni, 2022; Fereidooni and Khajevand, 2018; Ghobadi and Fereidooni, 2015; Yagiz 2018). Some of these changes are aimed to enhance their weathering rate and assess more accurately their degradation behavior and to better reflect environmental conditions of specific projects (e.g. Selen et al., 2019; Jamshidi and Sedaghatnia, 2023).

In the current research, preliminary results of slake durability tests conducted on dolomitic samples from Indiana are presented. These rocks are used as local construction materials, and form part of one of the hydrologic units that compose the carbonate-aquifer system of the Midwestern Basins and Arches Region in the Midwest (Casey, 1994). The durability tests were conducted following an ASTM D4644-16 adapted method, and a modified version that includes longer exposure of samples to immersion in the slaking fluid to achieve full saturation prior to the actual test. Both methods were extended to 10 cycles of wetting-drying to investigate the long-term slaking behavior of the samples. Slaking fluids of various pH values were also used. The main purpose of the project was the investigation of the effect of the number of wetting-drying cycles, pH of the slaking solution, and duration of immersion periods on slake durability index values in durable dolomite samples. The ultimate goal was to compare both methods, to determine if the modified method works better in the assessment of long-term durability of carbonate rocks.

## 2 MATERIALS AND METHODS

The Salamonie dolomite is a Silurian unit that includes impure argillaceous limestone, dolomitic limestone and shale in its lower stratigraphic levels, and coarse grained bioclastic vuggy dolomite that dominates in its upper sections in northern Indiana (Shaver et al., 1986). The Salamonie can reach 76 m thickness in northeastern Indiana, and it has been correlated with similar rocks in Illinois, Ohio, Kentucky, Michigan and Wisconsin (Shaver et al., 1986). Samples used in this research are from the vuggy variety, from which 40-50 g lumps were chosen for slake durability tests. Each sample consisted of 10 lumps, that were made blunt with a rock saw.

To evaluate the degradability of carbonate (dolomitic) rocks under different pH conditions, distilled water, and pH3 and pH5 solutions were used as slaking fluids. The pH3 solution was prepared by diluting chloroacetic acid and sodium hydroxide in distilled water, while the pH5 solution was obtained by combining glacial acetic acid and sodium hydroxide with distilled water. The pH of the solutions was monitored daily using a pH-meter. For each type of slaking fluid, two sets of samples were selected, one of them to be tested according to an adapted standardized slake durability index test, and the other to a modified slake durability index test. These methods are explained later.

Prior to performing the slake durability tests, the porosity of the samples was determined following standard procedures (method for porosity determination using saturation, according to ISRM 1979). The resultant porosity values ranged between 4.28 to 8.75%. In addition, petrographic and X-ray diffractometry analyses were done on a limited number of samples for determination of their mineralogical and textural characteristics. The aim of this was to assess potential effects of mineralogy and texture on rock durability.

### 2.1 Mineralogical and Textural Characterization

X-ray diffraction analysis was done to semi-quantitatively analyze the mineralogical composition of a limited number of samples. Bulk powder analysis, identification and quantification of the mineral phases was conducted at the Illinois State Geological Survey Geochemistry Lab. The analysis shows that the samples are almost pure dolomite (~99%), with minor amounts of magnesium calcite (~0.5%), and potassium feldspar (~0.5%) (Figure 1a).

In thin section, a mosaic of euhedral to subhedral dolomite crystals 0.1-0.2 mm in size have subplanar and straight boundaries. Clear dolomite crystals (Figure 1b) occur as uneven pore-lining cement in larger fenestral pores (vugs). Additionally, large (0.4 to 1.5 mm long) euhedral to subhedral cement crystals are mostly filling moldic porosity and fenestrae and can be distinguished from the replacement dolomite crystals because of its clear and transparent appearance under the petrographic microscope. Vugs are very heterogeneous in shape and size, from 0.1 to several mm long. Fossil pseudomorphs are also variable in size, from 0.3 to 1.5 mm in length.

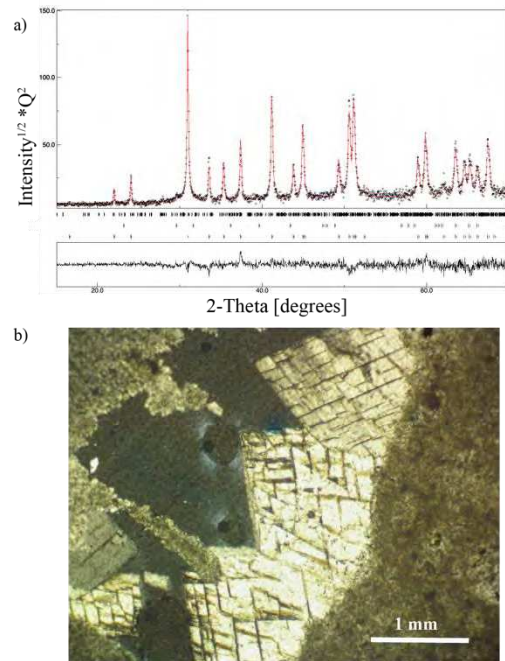


Figure 1. Mineralogical and chemical composition of a representative sample object of this study: a) Diffractogram of a sample with peaks corresponding to dolomite, albite and magnesium calcite and b) optical microphotograph from a thin section showing a vug (dark area) lined with clear dolomite crystals.

### 2.2 Slake Durability Tests

In the standard slake durability index test, originally developed by Franklin and Chandra (1972) for soft argillaceous rocks, the samples are initially dried (usually for 2-6 hours) in an oven at 105°C until a constant weight is achieved (ISRM, 1979; ASTM D464416). Then, the samples are introduced in a drum half immersed in water, that is rotated for 10 minutes at 20 rpm. The samples are dried in the oven again and weighed. The ISRM (1979) and ASTM D4644-16 (2016) defines the slake durability index (SDI) as the percentage ratio of the final to initial dry sample masses after 2 standard cycles of wetting and drying. This standardized procedure did not lead to significant degradation in the dolomitic samples used in the present research, and therefore the test was slightly modified and termed as “adapted standard method”: the procedure was extended to 10 cycles, and the

samples were pre-soaked for an hour before each slaking test. Also, the samples were initially dried at 30°C (instead of 105°C) with the aim of avoiding initial drastic volume changes and therefore microfracturing, since dehydration caused by high temperatures could also contribute to the formation of tension cracks and internal stresses in rocks (Hu et al., 2017). An additional set of tests were conducted by modifying a few parameters of the “adapted standard method” (“modified standard slake durability test”) to study the effects of longer soaking exposure in the samples.

### 2.2.1 Adapted Standard Slake Durability Test

The adapted standard method tests were carried out through the following steps: before each test, the 10 rock lumps were photographed, described, and weighed (Figure 2a). Then, the sample was introduced in a drum with a standard 2-mm mesh and dried during 8 hours at 30°C to a constant weight. Next, the drum and sample were mounted in the slaking trough filled with distilled water at room temperature (the water fills the trough to 20-mm below the drum axis, according to ASTM D4644-16). The sample was soaked in the drum for an hour, after which the drum was rotated for 10 minutes at a constant rate of 20 rpm. The drum plus the retained portion of the sample was removed from the slaking container, oven dried at 105°C to a constant weight, cooled and weighed. As mentioned above, this procedure was repeated 10 times (10 wetting-drying cycles) per sample. The drum plus the retained portion of the sample was used to calculate the Slake Durability Index ( $SDI_{astdi}$ ) after each cycle. This was expressed as a percent ratio of the final to the initial dry weight of rock sample in the drum:

$$SDI_{astdi} = \frac{W(D+S_i) - W(drum)}{W(D+S_0) - W(drum)} \times 100 \quad (1)$$

where,  $SDI_{astdi}$  is the slake durability index after each cycle ( $i=1$  to 10),  $W(D+S_i)$  is the weight of the drum and the solid sample retained in the drum after cycle  $i$  (1 to 10), and  $W(D+S_0)$  is the weight of the drum and the initial solid sample. Finally, the 10 rock lumps were photographed to assess shape changes in addition to the weight changes (Figure 2b).

To enhance the degradability of the dolomitic samples, the adapted standard test (ISRM 1979 and ASTM D4644-16) and the steps mentioned above were repeated on new specimens but extending the duration of the rotation cycles to 20 minutes and using slaking fluids with pH3 and pH5 values

### 2.2.2 Modified Standard Slake Durability Test

In a modified test, similar steps to the adapted slake durability test described in the previous section were followed, with a few different conditions: prior to the test and before each cycle, the samples were soaked in distilled water overnight (for a minimum of 8 hours). In each cycle, the drum was rotated for 10 minutes at 20 rpm after which the samples were oven dried overnight (for a minimum of 8 hours) at 30°C to a constant weight. This method was repeated on new specimens but increasing the duration of the tumbling cycles to 20 minutes and using slake pH3 and pH5 fluids. Similar to the adapted standard method, the Slake Durability Index of the modified method ( $SDI_{mod}$ ) was calculated after each cycle as the percent ratio of the final to the initial dry weight of sample in the drum. The samples were also photographed before and after the tests to document the degradation (Figure 2c and d).

## 3 EVALUATION OF RESULTS AND DISCUSSION

The SDI is a measure of the rock durability, since it indicates its degree of resistance to degradation when exposed to wetting-drying cycles, abrasion and chemical weathering. Samples with high SDI values have higher durability than samples with low SDI values. Degradability is closely related to the rock strength, mineralogy, and textural characteristics, such as crystal shape and size, crystal area, and effective porosity, among others (Gupta and Ahmed, 2007; Yagiz 2011a, 2018). The slake durability index also decreases with increasing porosity and water absorption (Khajevand and Fereidooni, 2022). In this work, samples with a relatively homogeneous composition (dolomitic) were tested to assess the influence of parameters such as the pH of the slaking fluid, the duration of the tumbling cycle, and the influence of a longer soaking period in the degradability of samples.



Figure 2. Visual signs of weathering in dolomitic samples before and after two different slake durability tests; a) rock lumps before the test; b) post-test picture of the same sample after 10-cycles following the adapted standard method with a pH5 slake fluid; c) rock lumps before and d) after 10-cycles following the modified method with a pH5 slake fluid.

### 3.1 Effect of pH

According to the results obtained from the two methods (adapted standard and modified), samples exposed to distilled water have the highest SDIs (98.30 to 99.02%) while samples exposed to pH3 slaking fluids have the minimum SDI values (85.44 to 87.84%) after ten cycles of the test (Figures 3a and b). Therefore, in both types of tests it has been observed a direct correlation between the pH of the slaking fluid and the amount of degradation ( $SDI_{astdi}$ , and  $SDI_{mod}$  values): the lower the pH, the lower the durability of the dolomitized samples. This is consistent with previous observations in carbonate rocks such as travertine, limestone, and dolomite (Singh et al., 2006; Gupta and Ahmed, 2007; Fereidooni and Khajevand, 2018, 2019; Khajevand and Fereidooni, 2022; Torabi-Kaveh et al., 2022) and is the result of the high susceptibility of carbonate rocks to get dissolved in contact with acidic fluids. The chemical reaction of the carbonate with the slaking fluid reduces the bond strength between the different chemical elements forming part of the rock, resulting in the reduction of its strength.

By plotting the SDIs calculated for each cycle, the slaking evolution of samples during the test can be assessed (Figures 3a and b). Samples tested with both, the adapted standard and modified methods show faster degradation rates at lower pH values (steeper slopes of the SDI-10 trends). Also in both methods, as the number of cycles increases, the SDI values decrease. But while the decreasing rate of specimen weight loss < 2-mm is almost linear in samples that were tested with slaking fluids of high pH values (distilled water and pH5), samples tested in pH3 fluids show a faster decreasing rate of SDI in the initial cycles than in the end cycles (Figures 3a and b). The linear trends obtained for tests at high pH values differ from Fereidooni and Khajevand (2018) and Khajevand and Fereidooni (2022) results, in that they show patterns of faster SDI decreasing rates in the initial cycles vs. the end cycles in dolomitic limestone tested in pH7, pH5.5 and pH4 slaking fluids. These disparities are likely related to the different mineralogical composition of their samples, richer in softer calcite (~55%) vs. the more insoluble (almost pure) dolomite samples tested in this work. For instance, while Khajevand and Fereidooni (2022) report values of 95.88-96.46% SDI values for tests in pH7 slake fluids, 98.30 to 99.02% SDI values are obtained in this research from tests with distilled water. The stronger resistance of dolomite to degradation compared to limestone has also been reported by Yagiz (2018).

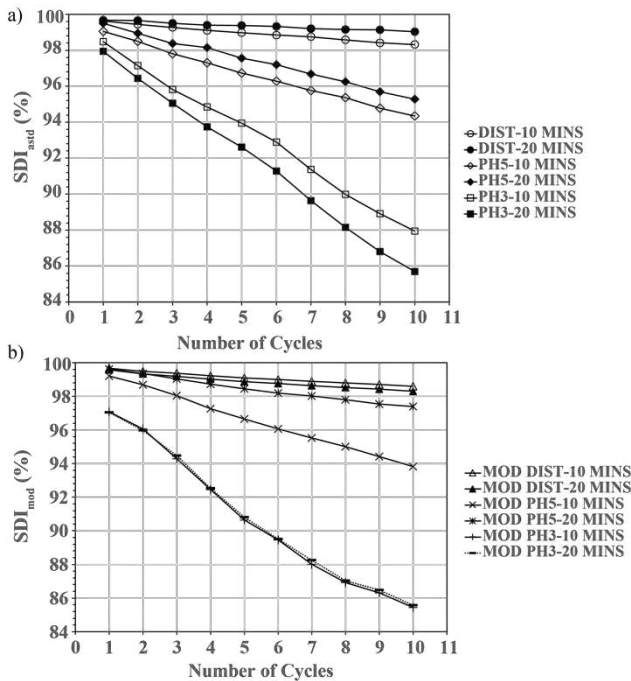


Figure 3. Slaking evolution of the dolomitic samples tested a) with the adapted standard method; b) with the modified method. PH values and tumbling durations are indicated in the legends.

On the other hand, Jamshidi and Sedaghatnia (2023) show marked SDI decreasing rates not only in the initial cycles of distilled water slake durability tests in limestone but also in dry durability tests. This suggests that the initial fast SDI decreasing rates in tests using high pH fluids reported by some authors is not

entirely due to rock-fluid chemical reactions, but soft limestone samples may be particularly affected by physical abrasion during the first cycles of the test.

### 3.2. Effect of Longer Soaking Exposure (Comparison of Adapted Standard vs. Modified Methods)

At equal conditions of pH and tumbling duration, SDI values obtained from the modified method ( $SDI_{mod}$ ) are generally lower (Figures 4a and b), except for samples tested in distilled water exposed to 10 minutes of tumbling and an anomalous sample tested in pH5 slaking fluid exposed to 20 minutes of tumbling. The slightly lower durability of samples in the modified method is likely related to the longer soaking period, that ensures full saturation of samples in the slaking fluid before the drum rotation phase. This is consistent with slake durability indexes being inversely correlated with water absorption (Fereidooni and Khajevand, 2018; Khajevand and Fereidooni, 2022). The longer exposure of samples to the fluids also affects the rate of degradability, since the slopes of the trends in the modified tests are generally steeper than those obtained with the adapted standard method (Figures 3a and b). Also, in tests conducted at equal conditions of pH and tumbling duration, the difference in slopes from the trends obtained with the two methods generally decreases with pH (the lower the pH, the closer the slopes obtained by both methods), to the point that trends obtained from both methods conducted with pH3 slake liquids and 20 minutes of tumbling are very close (Figure 5). This suggests that when the acidity of the slaking fluid is high, chemical degradation is fast, even if the soaking duration is limited (adapted standard method), and therefore it must be the main contributing factor to degradation of the samples.

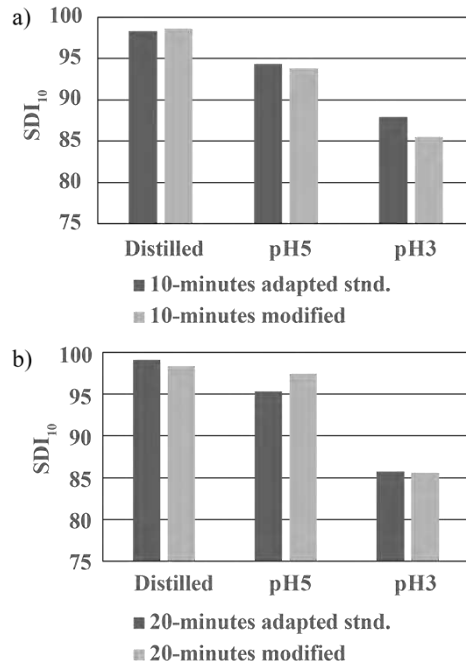


Figure 4. Comparison of slaking durability indices after the 10th cycle for a) 10-minute tumbling tests and b) 20-minute tumbling tests.

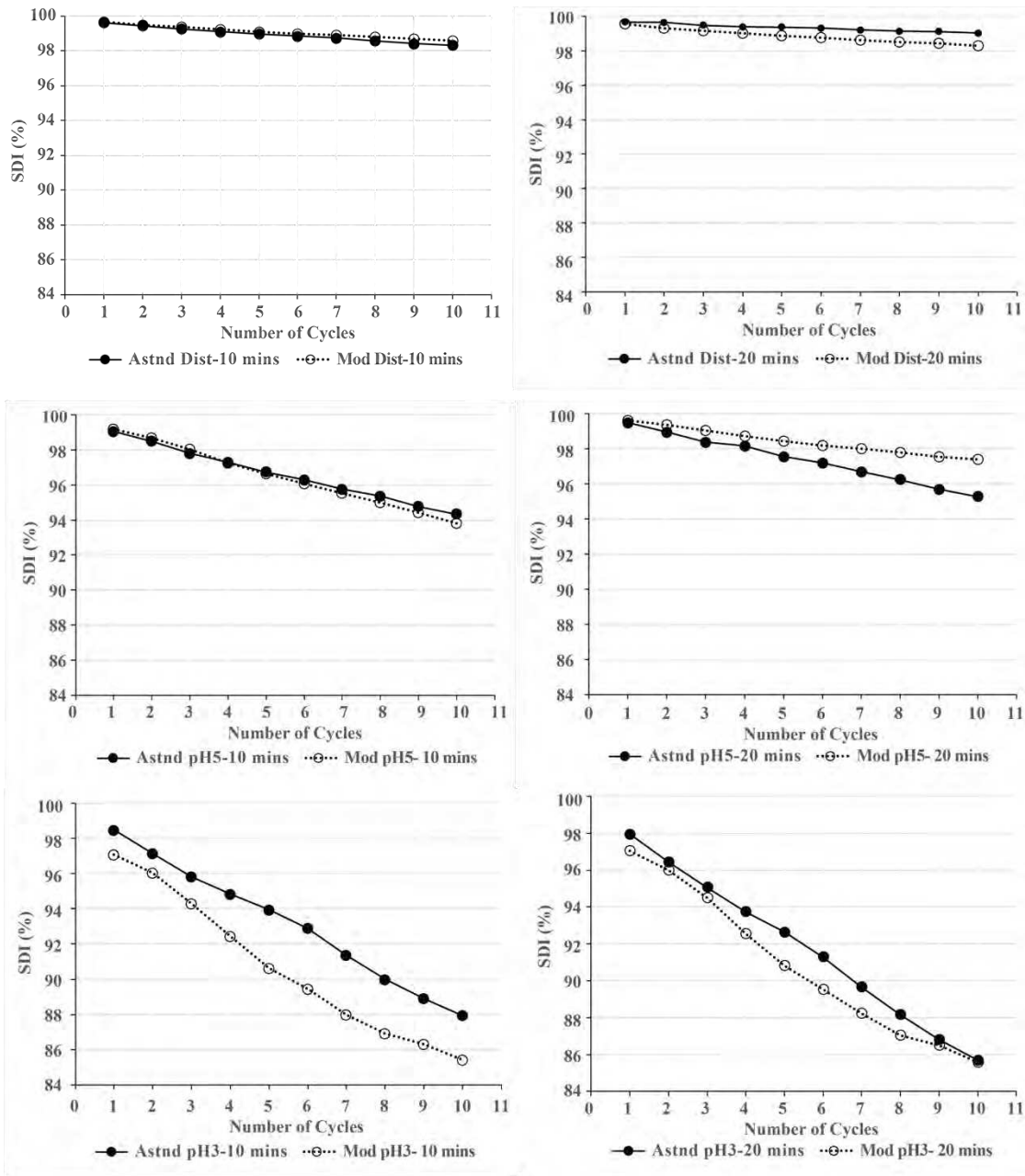


Figure 5. Comparison of slaking rates between adapted standard method (Astnd) and modified method (Mod) tests. Tumbling duration and the pH of the slaking fluid are also shown in the legend of the graphs.

### 3.3 Effect of Duration of Tumbling

#### 3.3.1 Adapted Standardized Slake Test Results

For samples tested in distilled water and pH5, there is no correlation between tumbling duration and  $SDI_{astnd}$  (Figure 6a). In fact,  $SDI_{10astnd}$  values are lower in samples exposed to 10 minutes

of tumbling than those exposed to 20 minutes. This is counter-

intuitive, since a longer exposure to both, water and abrasion should result in lower SDI values. This suggests that for conditions that include a high pH slaking fluid and limited wetting exposure, a longer period of abrasion does not necessarily contribute critically to the degradability of the samples. In fact, in tests

involving distilled and pH5 slaking fluids, the rate of degradability (slope of trends) is slightly faster at 10-minute than at 20-minute tests (Figure 3a). Therefore, as Torabi-Kaveh et al. (2022) suggested, for indurable rocks the duration of the cycle is not an important parameter in rock durability assessment. This also means that in the adapted standard tests the chemical reactions between the slaking fluids and the rocks were not strong enough to weaken the structure of the lumps and chemical reactions are independent on both sets of samples (10 and 20 minutes). Since samples are exposed to a very limited wetting phase in the adapted standardized test, the degree of saturation of the lumps is expected to be variable and inhomogeneous, and therefore an unknown percentage of the sample material is exposed to the slaking effect (Selen et al., 2019).

On the other hand, since the mineralogy of the samples tested in this study is rather homogeneous, their durability must depend on their individual texture (e.g., crystal size, percentage of cement vs. dolomite crystals, presence of micro-fractures or distribution of porosity in individual lumps) and the processes derived from wetting-drying cycles. This is consistent with Yagiz (2018) and Torabi-Kaveh et al. (2022) observations, that indicate that carbonate rock disintegration is high in a severe acidic environment (pH < 4), however for slaking fluids with a pH > 4, the degradability rate is not predictable and depends on rock properties such as texture, strength, and porosity. For instance, it has been previously shown that coarse grained carbonate rocks are less susceptible to chemical degradation than fine grained carbonate rocks (Gupta and Ahmed, 2007).

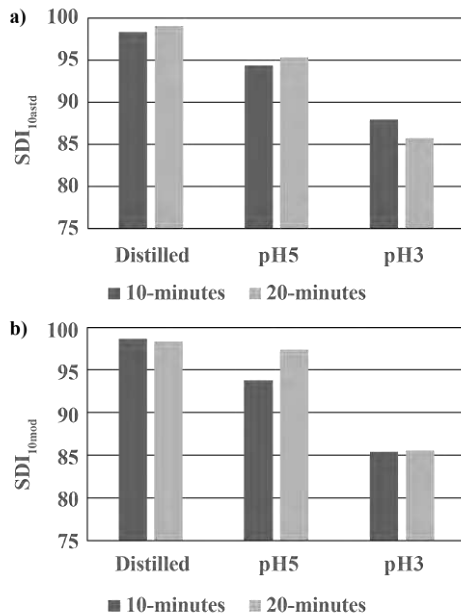


Figure 6. Comparison of the effect of tumbling duration in slake durability indices after the 10th cycle for a) adapted standard method tests and b) modified tests.

Also, the percentage of porosity, its distribution throughout the dolomitic samples as well as its degree of connectivity (permeability) may be a determinant factor in the observed random slake behavior at high pH values. For instance, in a previous research, degradation of low (0.79-1.39%) porosity limestone

samples in slake durability tests with water (non-acidic pH) has been attributed solely to rock lumps abrasion (Jamshidi and Sedaghatnia, 2023). This contrasts with results from this work, where samples with porosity ranging from 4.28 to 8.75% tested with high pH slake fluids are showing more vulnerability to wetting and drying cycles than to physical abrasion derived from longer duration periods of tumbling.

Samples tested in pH3 slaking fluid show lower durability when exposed to larger tumbling phases (20 minutes) vs. tumbling at 10 minutes (Figure 6a), suggesting that in stronger acidic environments the chemical reaction considerably weakens the lumps, making them more vulnerable to longer physical abrasion, as suggested by Yagiz (2018) and Torabi-Kaveh et al. (2022). In addition, the slopes of the 10 vs. 20-minute SDI<sub>lastd</sub> trends (Figure 3a) are significantly different, with the 20-minute tumbling test being considerably steeper. This supports the fast chemical weathering rate as the main contributing factor to degradation of samples, since the mere 10 additional minutes of exposure to the acid solution per cycle in the 20-minute tumbling tests suffices to have a significant effect in the rate of degradability of the samples. Therefore, at pH3, chemical and physical processes are important in the degradability of samples.

### 3.3.2 Modified Slake Test Results

Samples tested according to the modified method were submerged for several hours before each cycle. This extensive wetting phase likely ensured a more homogeneous degree of saturation and therefore a larger amount of the sample exposed to slaking effects. As a result, samples became more vulnerable to physical abrasion, and longer duration of the tumbling process (20 minutes) produces slightly lower SDI<sub>mod</sub> in samples exposed to distilled water (Figure 6b). In addition, the rate at which the degradation occurred in both tests (distilled water, 10- vs. 20-minutes tumbling) is very similar (similar slopes in both trends, Figure 3b). This suggests that with higher durations of immersion, chemical and physical processes are both important in the degradability of samples. The anomalous high SDI<sub>mod</sub> of sample subjected to pH5 and 20-minutes of slaking test is likely related to the textural characteristics of the lumps. In samples subjected to pH3 slake fluids, 10-minute vs. 20-minute SDI<sub>mod</sub> values are very similar (Figure 6b). Tumbling the samples for 10 additional minutes does not introduce significant differences in SDI values, and the rate at which degradation occurs is also very similar (Figure 3b). This likely implies that the larger exposure of samples to the strongly acidic fluid is the most important factor in the test (as previously stated for the shorter duration of soaking periods) and once the lumps are severely weakened due to the long exposure to chemical weathering, the physical abrasion process does not add a significant component of degradation. Once a certain level of weakness is achieved due to the most soluble components of the rock already dissolved, the remaining structure of the samples may present a similar level of resistance to physical weathering, and they tend to weather at similar rates.

## 4 CONCLUSIONS

In this study, dolomitic samples were subjected to slake durability tests following an ASTM D4644-16 adapted method, and a modified version that includes longer exposure of samples to immersion in the slaking fluid. Both methods were extended to 10 cycles of wetting-drying. The tumbling period was also extended

to 20-minutes in some of the tests, and slaking fluids of various pH values were used. Therefore, effects of the wetting-drying cycles, pH of the slaking solution, and duration of immersion and tumbling cycles in the slaking behavior of the dolomitic samples was investigated. Based on the results, certain conclusions can be drawn:

- Adapted and modified slake durability test results show that samples tested with slaking fluids with low pH values (pH3), there is a larger degree of degradation (highest material loss that is < 2mm) and generally the weathering reactions progress faster (steeper slopes in Slake Durability Index trends).
- If the pH of the slaking fluid is high (distilled water and pH5), the decreasing rate of specimen weight loss < 2-mm is almost linear, in contrast with samples tested in pH3 fluids that show a faster decreasing rate of SDI in the initial cycles than in the end cycles.
- Most of the SDI values obtained from the modified method (longer slake fluid exposure) are generally lower than those obtained from the adapted standard method which is connected to full saturation of samples and their higher exposure to slaking effects. Longer immersion periods also affect the rate of degradability, resulting in steeper slopes in the SDI trends. However, if the fluid is strongly acidic (pH3 in this study), the soaking duration is not as relevant, since even at limited slaking liquid exposure times, dissolution occurs fast and is the main contributing factor to degradation of the samples.
- With limited exposure to high pH slaking fluids (distilled water and pH5), a correlation between tumbling duration (abrasion) and SDI has not been observed. Therefore, in agreement with Yagiz (2018) and Torabi-Kaveh et al. (2022) results in this research show that for slaking fluids with a pH >4, the degradability rate of the samples is not predictable and depends on rock properties such as texture or porosity. However, if the fluid is strongly acidic (pH3 in this study), limited fluid exposure duration is sufficient for chemical reactions to weaken carbonate rocks, making them more vulnerable to longer physical abrasion periods.
- Longer immersion times in high pH slaking fluids make samples vulnerable to physical abrasion and both chemical and physical processes are important in the degradability of the samples during the modified tests. However, samples immersed for longer periods in pH3 slaking fluids do not show significant variation in SDI values with increasing abrasion (tumbling time). This suggests that in the modified test and at low pH values chemical weathering is the most important factor in the degradation process of samples.

Since these observations are based on a limited number of samples, additional investigations are needed to assess the full validity of these results, and to formally establish correlations. However, these results contribute to the understanding of the combined effects of pH, physical abrasion, and immersion times in

the durability of dolomitic samples.

## 5 ACKNOWLEDGEMENTS

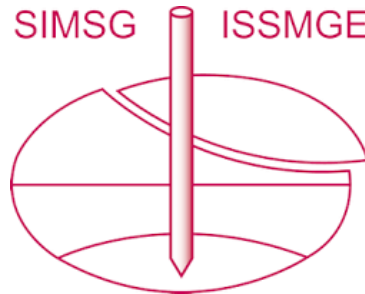
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